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Department of the Environment, Transport, Energy and Communication DETEC

Swiss Federal Office of Energy SFOE
Energy Research

Final report

Investigation of Inductive Charging Systems

IEA 4E Electronic Devices and Networks Annex (EDNA)

Date: 14. September 2017
Town: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Research Programme «Electricity Technology»
CH-3003 Bern
www.bfe.admin.ch

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SFOE contract number: SI/501557-01

Zusammenfassung

Die Elektromobilität findet zunehmende Verbreitung. Der wirkliche Durchbruch hängt jedoch nicht zuletzt von der zur Verfügung stehenden Ladeinfrastruktur ab. Während das Netz konduktiver Ladestationen (Energieübertragung auf das Fahrzeug über ein Kabel) ausgebaut wird, steht die induktive Ladetechnik (berührungslose Energieübertragung) noch am Anfang. Für das induktive Laden werden allgemein drei verschiedene Szenarien unterschieden: Erstens, das «static charging», bei welchem das Fahrzeug an Ort und Stelle über einen längeren Zeitraum geladen wird und der Fahrer das Fahrzeug dabei verlässt. Zweitens, das «stationary charging», bei dem über eine Dauer von bis zu einigen Minuten geladen wird, der Fahrer jedoch das Fahrzeug in der Regel nicht verlässt. Und Drittens, das «dynamic charging», bei welchem das Fahrzeug während der Fahrt geladen wird. Für alle drei Varianten unterscheidet sich die Infrastruktur.

Allgemein sind wenig öffentlich verfügbare Daten vorhanden zum Thema Effizienz und Standby-Verbrauch. Dies deshalb, da es erst wenige kommerziell erhältliche Systeme gibt und wichtige Grundlagennormen sich noch in der finalen Entwicklungsphase befinden. Für «heavy-duty-vehicles» wie z.B. Linienbusse gibt es mehr Informationen und Anlagen im Betrieb, da dieses Anwendungsszenario enger definiert ist. D.h. Busse ähneln sich mehr im Aufbau und im Fahrprofil als Autos, was zu einer Vereinfachung der Systeme führt.

Allgemein kann festgehalten werden, dass sich die Standby-Verluste wohl nur geringfügig unterscheiden im Vergleich mit konduktiven Ladesystemen. Die Effizienz beim Laden (Effizienz der Energieübertragung vom Netz bis zum Batterieanschluss) liegt tendenziell ein paar Prozente tiefer als bei konduktiven Systemen. Obwohl ein induktives Ladesystem hocheffizient betrieben werden kann, leidet der Wirkungsgrad systembedingt unter dem Einfluss der nicht immer genau passenden Ausrichtung von Sender- und Empfängereinheit zueinander.

Summary

Electro mobility is becoming increasingly popular. The ultimate break through depends to a significant degree on the available charging infrastructure. While the network of conductive charging stations (energy transfer to the vehicle through wires) is increasing, inductive charging (contactless energy transfer) is still in its infancy. Inductive charging includes three different scenarios. Firstly, «static charging», where the vehicle remains parked over an extended period of time and the driver typically leaves the vehicle. Secondly, «stationary charging», with a duration of a few minutes, where the driver routinely remains in the vehicle. Finally, «dynamic charging», where the vehicle is charged while moving. The required infrastructure differs significantly in each case.

Generally very limited publicly accessible data is available concerning efficiency and standby losses of inductive charging systems. Only a few products are commercially available and relevant standards for such systems are still under development. More information is available for inductive chargers intended for «heavy duty vehicles» such as city buses, as more systems are already in operation. City buses tend to have similar shapes and chargers can be optimized for a specific fleet within a limited geographical range.

A basic conclusion from this investigation is that the standby losses of an inductive charger differ only marginally compared to those of conductive charging. The power conversion efficiency (grid to battery)

tends to be sligtly lower for inductive systems. A highly efficient operation of a wireless charging system is technically possible, but the proper alignment of the vehicle with respect to the transmitter coil has a significant impact on the efficiency.

Contents

List of Abbreviations:

AC	Alternating current
CCS	Conductive charging system
DC	Direct current
EMI	Electromagnetic interference
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
FOD	Foreign object detection
ICS	Inductive charging system
HDV	Heavy-duty vehicles
HMI	Human machine interface
LDW	Low-duty vehicles
LOD	Living object detection
PFC	Power factor corrector
OEM	Original equipment manufacturer
WPT	Wireless power transfer

1 Introduction

With the increasing availability of electric vehicles, a well-developed charging infrastructure is imperative. While the number of conductive charging stations increases rapidly, the development of the inductive charging infrastructure is at a very early stage. This investigation particularly addresses their charging efficiency and standby losses. In this context, it is useful to distinguish between low-duty vehicles and heavy-duty vehicles as well as the charging scenarios e.g., duration and power level. Generally, the public availability of data is very limited. Furthermore, it is not always possible to perform a fair comparison of the data, as the standardization process regulating efficiency measurement procedures is still in progress.

Chapter 2 provides statistical data and estimations related to the growth of the numbers of electric vehicles in use as well as the required charging infrastructure. It also focuses on describing the charging technologies mostly available for conductive and inductive charging.

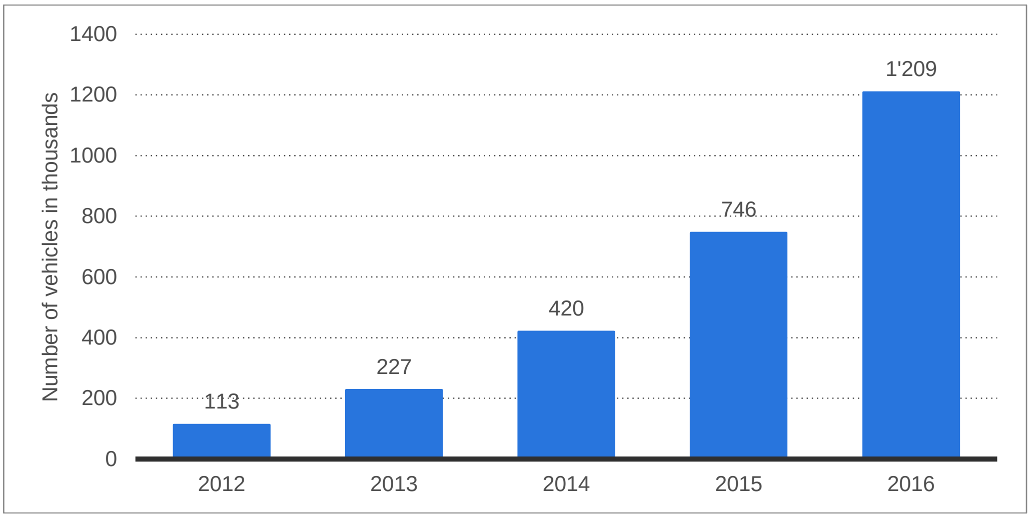
Chapter 3 presents a comparison between conductive and inductive charging, focusing on standby losses and charging efficiency.

Additional information concerning the possible impact of future charging systems is included in Chapter 4.

2 Electric Vehicle Supply Equipment

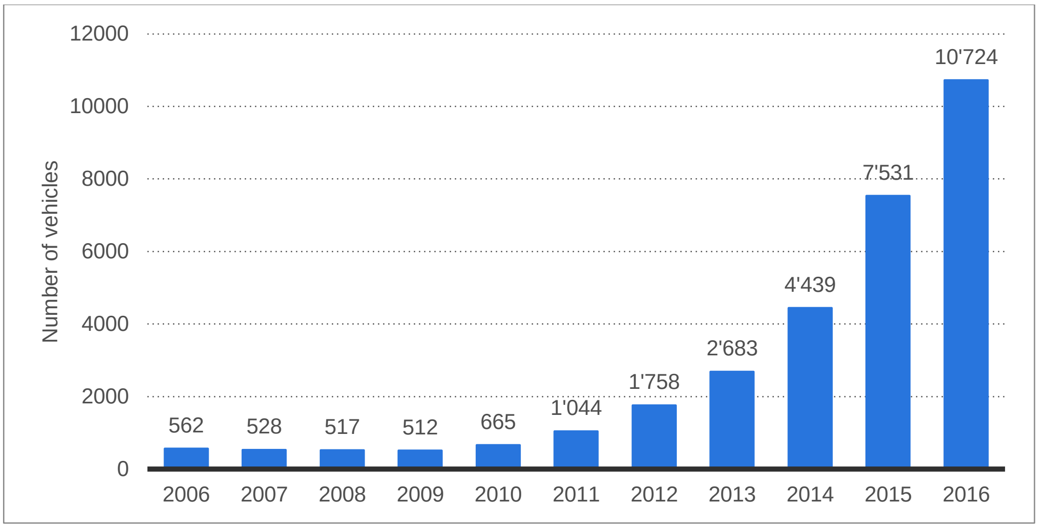
The total number of electric vehicles in use globally is increasing rapidly, as shown in Figure 1, with an annual increase of 81% since 2012. The figures for Switzerland are shown in Figure 2, with an annual growth rate of 57% over the same period. Despite this impressive growth, the electrically driven fleet contributes a very small portion to the total number of vehicles in use today.

Figure 1 – Number of electric vehicles in use worldwide.



Source: http://www.statista.com/statistics/270603/worldwide-number-of-hybrid-and-electric-vehicles-since-2009/

Figure 2 – Number of electric vehicles in use in Switzerland from 2006 to 2016.

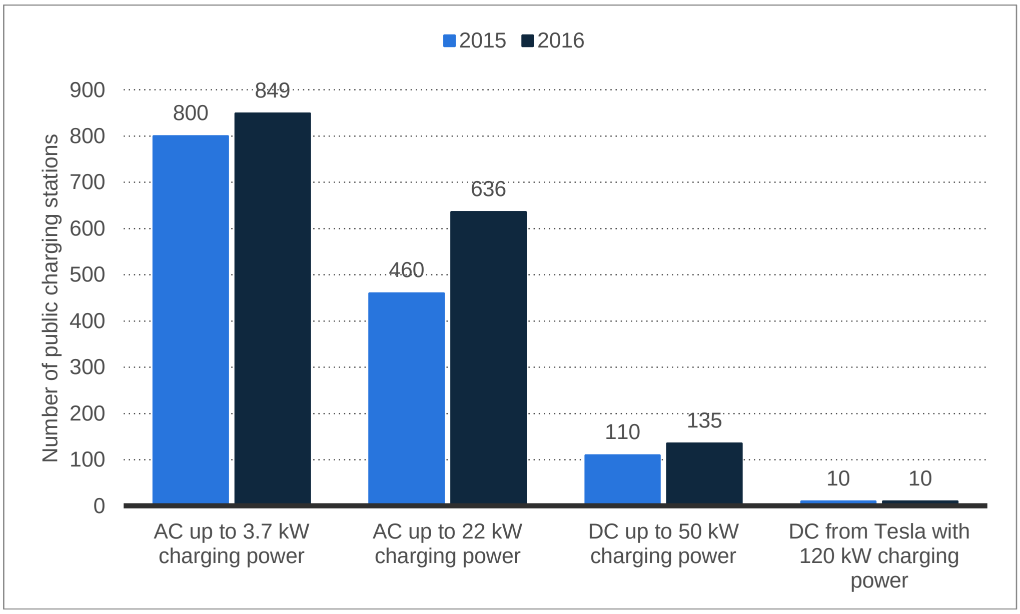


Source: http://de.statista.com/statistik/daten/studie/693236/umfrage/personenwagen-mit-elektroantrieb-in-der-schweiz

Concerning the charging infrastructure, there are numerous initiatives worldwide supporting the development of electric vehicle supply equipment (EVSE). A report on e-mobility was published by the Swiss federal council in 2015, and the follow-up project “Plattform Ladenetz Schweiz” (Charging network Switzerland) was initiated in 2016, to coordinate the expansion of the charging infrastructure in Switzerland, with a focus set on conductive systems. The goal is to coordinate and support the installation of a nationwide network with meaningfully chosen locations, securing access to users, and providing a standardized billing method among all charging stations. Figure 3 shows the development of publicly accessible EVSE in Switzerland for the years 2015 and 2016.

Worldwide a tremendous increase of EVSE is expected over the next years. The forecast for 2020 estimates 12.7 million charging stations. This is more than twelve-fold the number of 2014, when about 1 million of such stations were in operation. This corresponds to an annual growth of 53%[1].

Figure 3 – Public charging stations in Switzerland in the years 2015 and 2016.



Source: http://de.statista.com/statistik/daten/studie/685599/umfrage/oeffentliche-stromtankstellen-in-der-schweiz-nach-stromart-und-ladeleistung

2.1 Conductive Charging Systems – CCS

Currently conductive charging systems are the prevailing technology. The vehicle is connected by means of a cable and plug to the power supply for charging. Different power levels have been established for both, AC and DC charging, and even a combination of the two. The public charging infrastructure is primarily covering the needs of passenger cars, with numerous manufacturers developing and producing CCS. Most of the charging systems are commercially available. CCS chargers are generally classified in AC and DC systems; and furthermore divided into power classes. An overview is shown in Table 1:

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[1] Source: http://de.statista.com/statistik/daten/studie/431317/umfrage/ladestationen-fuer-elektroautos-weltweit

Table 1 – Power classes for conductive charging systems.

SAE J1772 Definition (USA)		
AC Level 1: 120V, 16A		2 kW
AC Level 2: 240V, 80A		19 kW
AC Level 3: (not specified yet)		>19 kW
DC Level 1	200–450 V	36 kW
DC Level 2	200–450 V	90 kW
DC Level 3	200–600 V	240 kW

IEC 62196 Definition (International)	
Mode 1: 1x230V / 3x400V, 16A	7.7 kW
Mode 2: 1x230V / 3x400V, 32A	15.4 kW
Mode 3: 3x400V, 32-250A	>20 kW
Mode 4: <1000V / 400A, (DC)	240 kW

Source: SAE J1772 Standard, and IEC 62196 / IEC61851-1 Standard respectively.

2.2 Inductive Charging Systems

Inductive charging systems (ICS) operate contactless, meaning there is no plug nor cable connection between the charging station and the vehicle. At this point, there are no adopted standards for a classification on the power level, as is the case for CCS. However, ICS could be classified according to other criteria. The two most common classifications are: by the type of vehicle to be charged, differentiating between low-duty vehicles (LDW) such as passenger cars and bikes; and heavy-duty vehicles (HDV) such as buses and cargo trucks. The second classification is based on the way the vehicle is charged:

Static Charging

The vehicle is not moving for a medium to long time, e.g., more than 5 minutes, and the driver does not intend to use the vehicle soon. Possible scenarios are parking at home or at the office.

Stationary Charging

The vehicle is not moving for a short time, e.g., less than 5 minutes, and the driver remains in the vehicle. Possible scenarios are traffic lights, bus stops, or delivery trucks.

Dynamic Charging

The vehicle is moving while being charged and the driver is in the vehicle. Possible scenarios are travelling on highways and on city streets.

From the viewpoint of its use, the ICS can also be divided in two groups. One is the low power charger mainly in private residences, where an EV is charged overnight. The typical power level for this application is 3.5kW. The second group consists of public charging stations, for example along freeways and in public parking lots. To reduce the charging time, the power level for the second case will generally be significantly higher, such as 22 kW or more.

3 Charging Process and Energy Consumption of EVSE

This section focuses primarily on charging, the energy consumption, and losses in the supply equipment. As of today only a few suppliers are manufacturing inductive charging systems, and therefore, only very few of them are commercially available for non-OEMs. Table 2 shows the major players in this field. PluglessPower is currently the only system, which is available for purchase.

Table 2 – Inductive charging system suppliers worldwide.

PluglessPower	https://www.pluglesspower.com/
Qualcom Halo	https://www.qualcomm.com/products/halo
Conductix Wampfler	http://www.conductix.ch
Kaist (Korea)	http://www.kaist.edu
Bombardier PRIMOVE	http://primove.bombardier.com
Momentum Dynamics	http://www.momentumdynamics.com
WiTricity	http://witricity.com/
Eaton HEVO	https://www.hevopower.com/
IPT Technology GmbH	http://www.ipt-technology.com
ORNL WPT (DOE Oak Ridge National Lab)	Licenses the technology to the private sector.

Most of the ICS are sold directly to OEMs, therefore, detailed specifications and efficiency data are not publicly available.

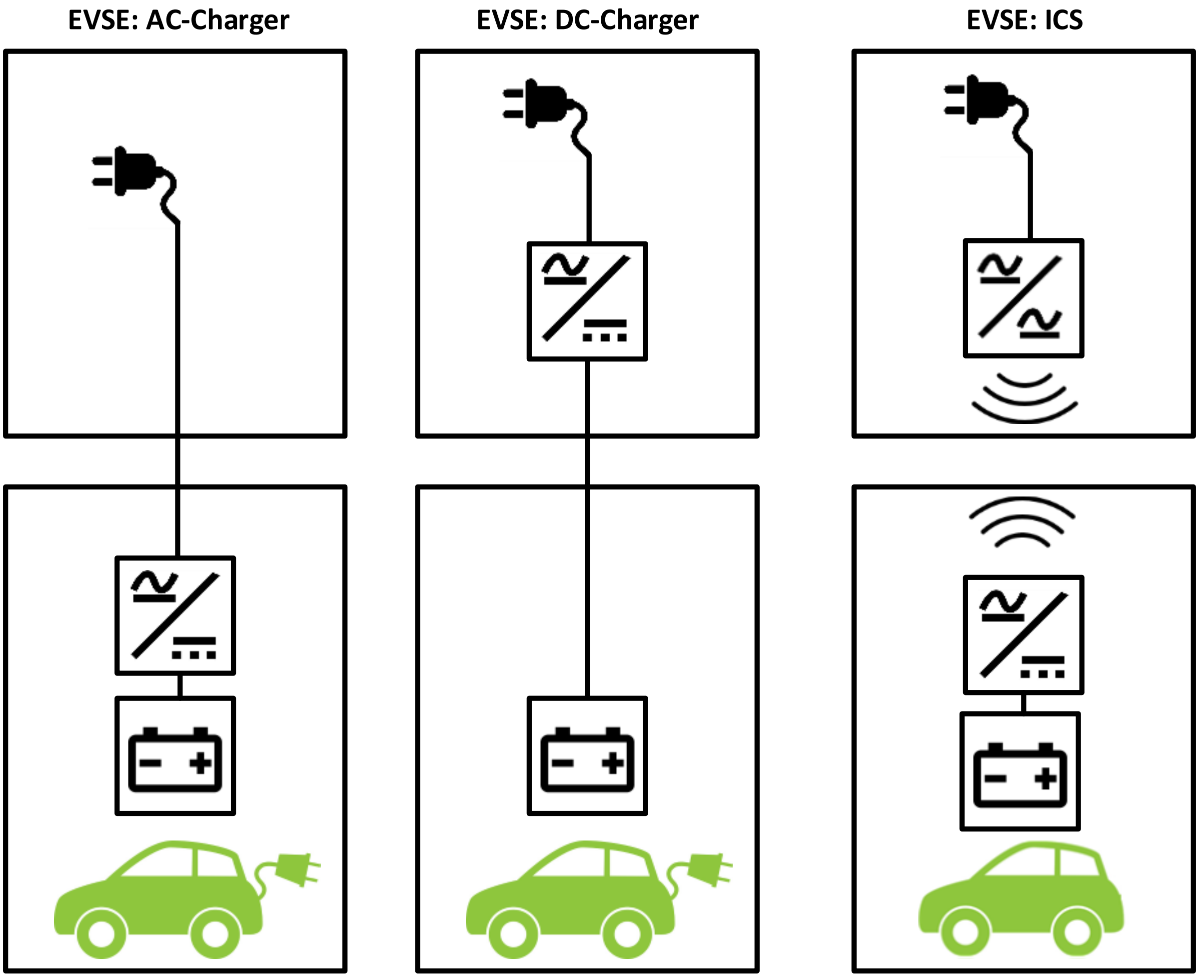
Based on available data for conductive charging systems, published data for various wireless charging systems, and own research at the NTB the consumption and power losses of the ICS were estimated and presented in the next section, for the different charging states and charging systems.

3.1 Principle and Types of Charging

All charging types under investigation have one principle in common: Energy provided by the AC grid is fed into a DC battery using modern power electronics circuits. Nevertheless, they differ in the location where the power conversion takes place, and with that, in the location where the losses occur. For the AC charging, the electric vehicle (EV) is directly connected to the power grid using an onboard charger. Typically, for higher charging power levels a DC charger is used. In this case, the power conversion takes place in the charging station itself and the EV is DC connected (e.g. Tesla Supercharger).

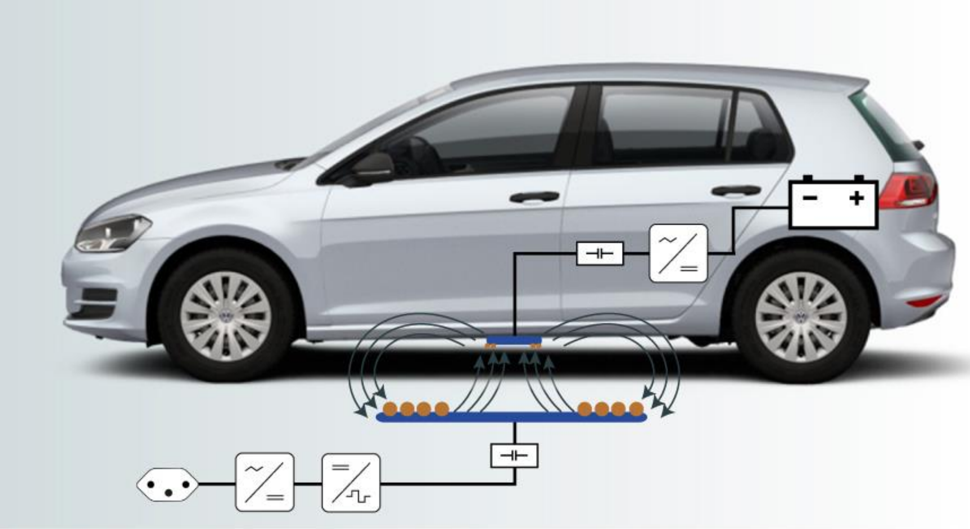
In general, there are power electronics circuits in the supply equipment, as well as on board of the electric vehicle. The three most common charging types are shown in Figure 4.

Figure 4 – Three types of EV charging.



In case of inductive charging, the transmitter circuit is installed in the parking lot or garage floor (for static charging), and the receiver circuit is fixed to the vehicle, as shown in Figure 5.

Figure 5 – Inductive charging components



Source: Shutterstock Contributor and NTB

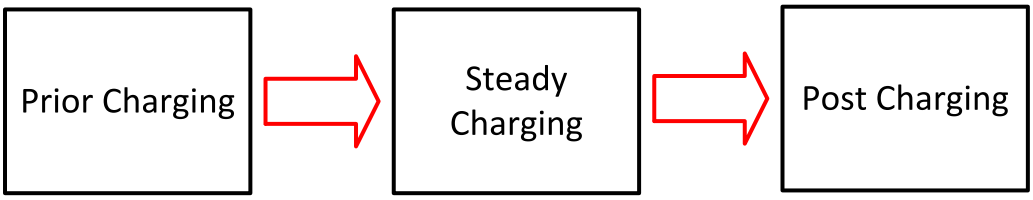
Depending on the power level the transmitter is connected to the single- or to the three-phase grid. A power factor corrector circuit (PFC) is generally necessary as it is required by international regulations to limit the harmonic currents fed back into the supplying grid. (This also applies to conductive charging).

The transmitter coil is situated on the floor beneath the vehicle, generating a strong magnetic AC field in order to transmit power to the receiver coil attached to the vehicle. In some ICS an additional onboard post regulator is used for battery management and controlling of the charging.

3.1.1 Charging States

The overall charging process for both, conductive and inductive charging systems can be divided into three states, as shown in Figure 6.

Figure 6 –Charging states of EVSE.



Prior Charging

The EVSE is in a standby mode (no charging is taking place) and is waiting to start the charging process. The HMI (Human Machine Interface) and user communication functions are active (WIFI/Bluetooth or similar communication interface to exchange user interaction data for convenience). With respect to this, there is no significant difference between AC, DC or inductive charging stations. In case of an ICS, a parking assistant may check for an approaching vehicle and navigate the driver to the best parking position. Heating and/or cooling capability may be required to ensure proper operation in a severe environment (e.g. -20°C in cold regions or +50°C in hot regions). These heating/cooling functions are also active during steady charging and possibly during the post charging process as well.

An auxiliary supply provides the power to cover the EVES’s own needs. This supply remains active in all charging states, and ensures that the EVSE is permanently powered.

Steady Charging

There are differences between AC, DC and inductive systems with respect to the location where the power losses are generated during the charging process. AC systems contain no power electronics in the charging station; the associated losses are concentrated in the onboard charger. In contrast, in DC charging stations the bulk of the power electronics losses appear in the (external) charging station. For the inductive charging systems the power losses are split between the stationary transmitter and the receiver on the vehicle.

The EVSE displays the current charging progress on the HMI and communicates with the EV to get the necessary system information. The charging process may last for a few seconds to minutes (e.g., steady or dynamic charging) or may take a few hours to fully recharge the battery.

Post Charging

After the charging process is completed, the EVSE is waiting for the EV to leave the parking position while the system communication, including the HMI, remains active.

3.1.2 Power Consumption of the Charging States

The prospective power consumption and power losses during the different charging states are shown in Figures 7, 8 and 9, with red colored blocks. The dashed blocks correspond to the sources of losses for inductive charging, which are generally not present in conductive charging.

In this section, the static or stationary charging situations are assumed. Reliable data on energy consumption and losses for dynamic charging is virtually non-existent, as the technology is very new. As of today, there are only few test sites worldwide for dynamic charging.

Figure 7 – Prior charging

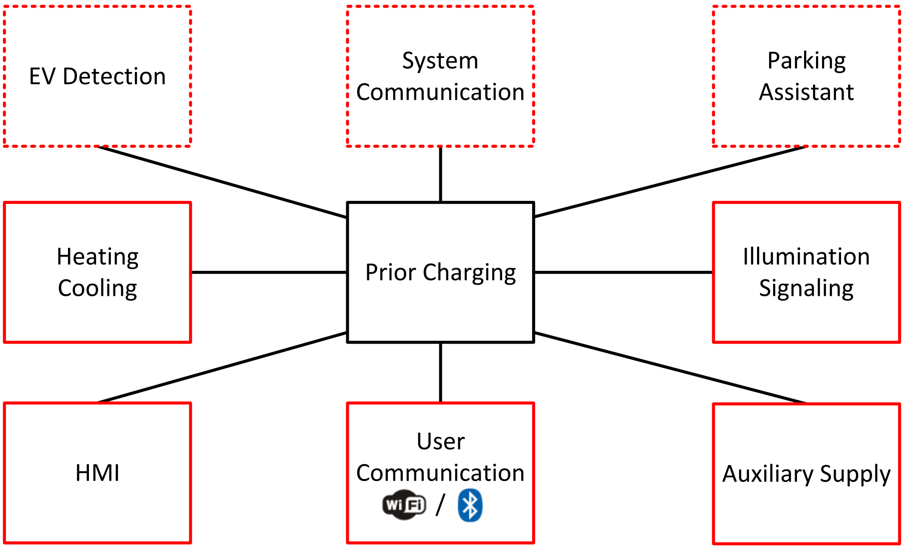


Figure 8 – Steady charging

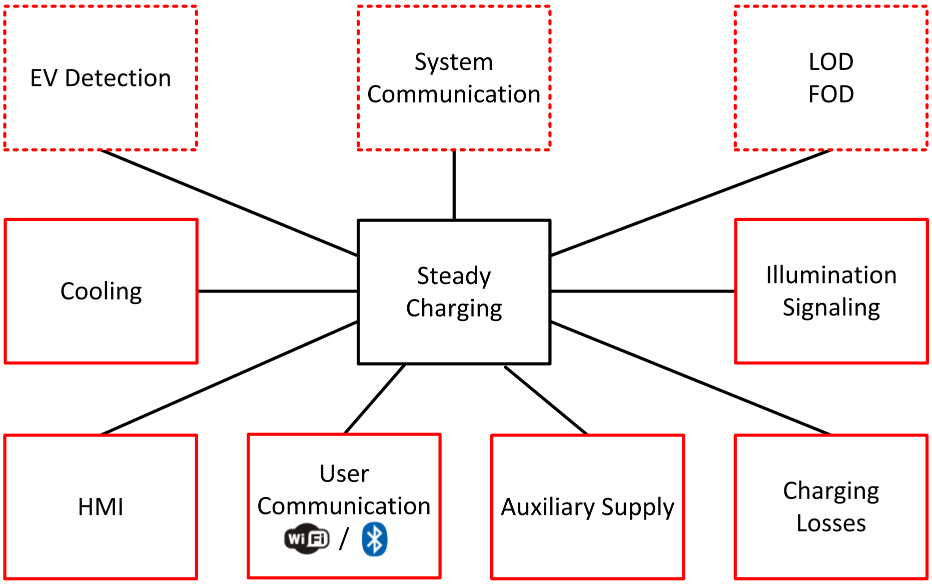
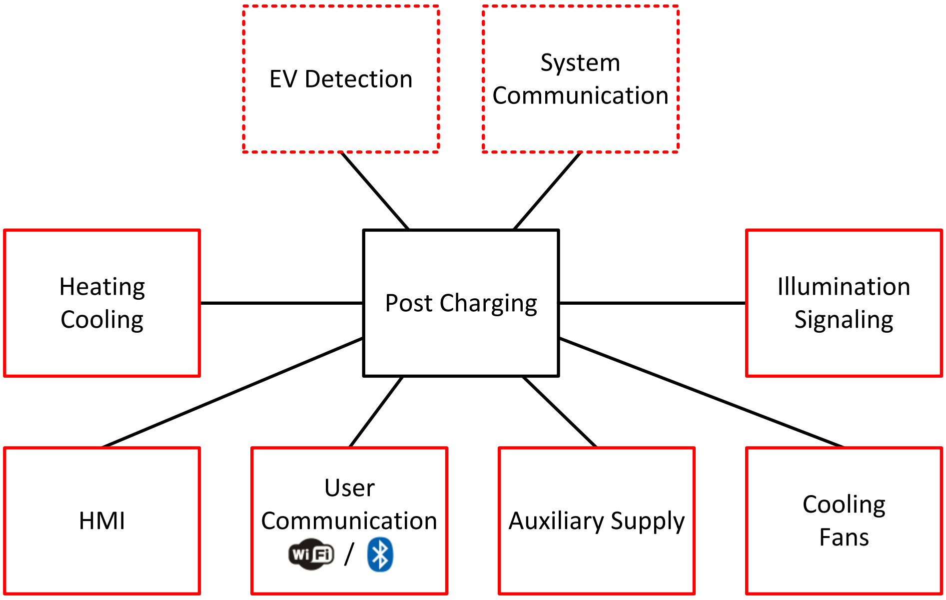


Figure 9 – Post charging



3.1.3 Power Consumption of Conductive Charging Systems

The main differences of ICS with respect to CCS are:

- The EV detection: Unlike in a cable-connected system, an ICS must recognize an approaching car on its own. This searching requires a constant minimal power level not present in a CCS.
- As the power electronics is divided in two parts – one stationary and one onboard – a more intensive communication is required in all three charging states for the ICS.
- In ICS the parking assistant to aid the proper positioning of the EV with respect to the transmitter coil, the living object detection (LOD), as well as the foreign object detection (FOD) also require power.

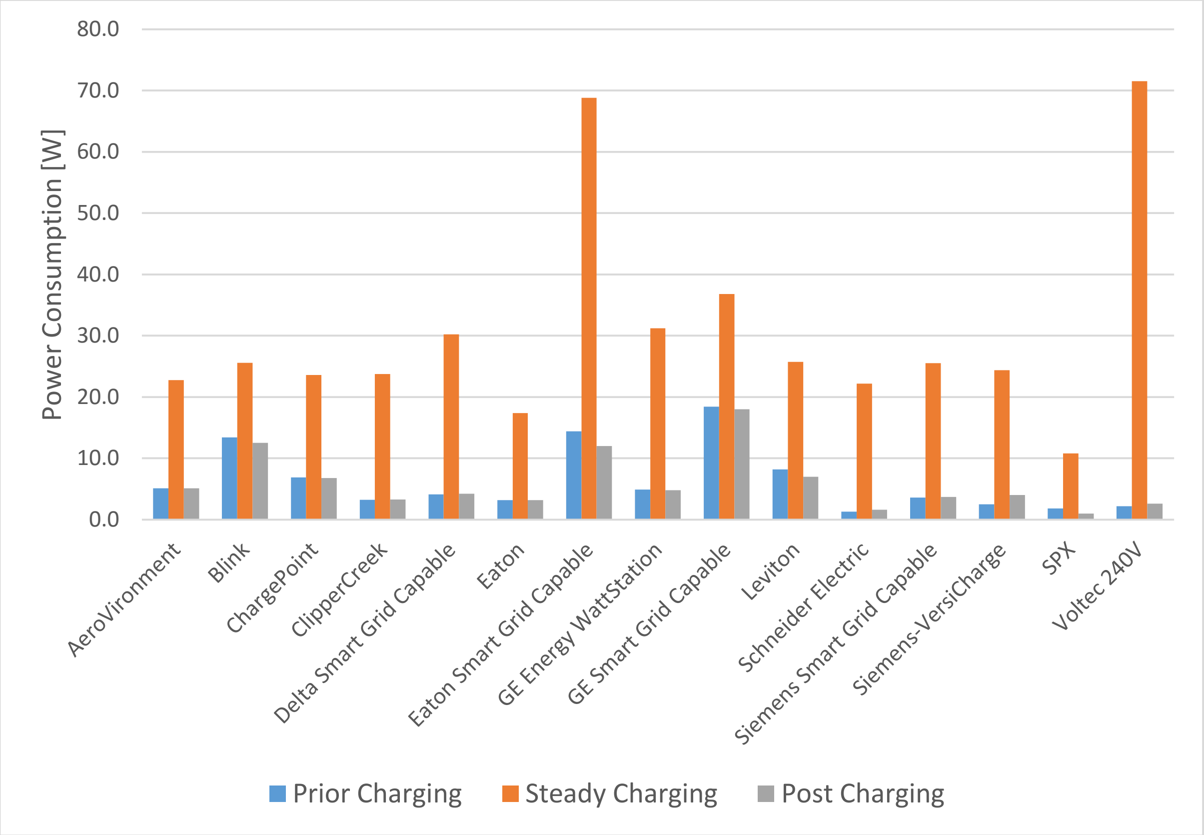
Typically common to both cases (ICS and CSS) are:

- A human machine interface (HMI) to display the battery and charging states and charging progress.
- The user communication.
- System cooling fans, and possibly a heater for severe ambient conditions.
- Illumination and signaling of the charging area.

Most AC conductive charging systems, where data is available (AC Level 2), consume 13W or less in the **prior charging state**, as shown in Figure 10. Higher power needs are due to additional EVSE features and their functionalities, e.g., heating/cooling of the system depending on the ambient conditions of the charger´s location, or illumination and signaling of the EVSE during night hours and outdoor use.

During the **charging state**, the power consumption is in most cases less than 30 W, with some exceptions reaching the 70 W range. Power electronic losses in the onboard charger are not considered in this case and are discussed separately. The difference between post and prior charging power consumption is minor, as shown in Figure 10.

Figure 10 – Typical power consumption for AC conductive charging systems.



Source: Own adaptation based on testing reports from https://avt.inl.gov/evse-type/ac-level-2.

Virtually no internal power consumption data for inductive chargers are available. At best, the power consumption for the prior and post charging states can be estimated, based on the (additional) functionalities necessary for inductive charging systems.

Prior Charging

It can be assumed that for prior and post charging states the inductive charging system consumes more power due to additional functionalities and features necessary for its operation. For example, an EV detection system must identify an approaching vehicle, and will initiate some type of system communication.

The efficiency of the energy transfer process of an inductive charger depends on the proper coupling between the transmitter and receiver coils (see Figure 5), and thus, a parking assistant is necessary during the prior charging state. This assistant communicates (over a defined communication protocol) with the vehicle, and collects information about the EV battery state and charging mode. These features add to the standby consumption of the inductive system.

For safety reasons a living object detection (LOD) and foreign object detection (FOD) must be active before and while the charging is in progress.

Today low power wireless communication protocols (e.g., Bluetooth, ANT+, ZigBee, WI-FI, NFC) help to keep the energy consumption low. An estimated 10 W additional power consumption is sufficient for an inductive charging system. That means, the standby losses will increase to roughly 20 W for the prior charging state[2]. In this state most of the electronics on the EV side are deactivated, with nearly no energy consumption.

An estimation of the power consumption for the heating and/or cooling functions for a proper operation before or during the charging process is difficult. This depends strongly on the environmental condition of the charger location.

Steady Charging

During the charging process the power electronics losses are dominant, and their extent depends on several factors, such as the level of transmitted power, battery voltage, air gap and alignment between transmitter and receiver. Other system functions such as communication, LOD/FOD and signaling require only an insignificant amount of energy compared to the charging losses, and therefore, are not relevant during steady charging. The system efficiencies for different chargers are shown in the next section.

Post Charging

After completion of the charging process, the supply equipment still needs to communicate with the onboard charging system to detect if the vehicle is still parked[3]. The system also receives information about the state of charge of the battery, e.g., if the battery is (fully) charged or not. These additional features on an ICS require an estimated additional 10 W of power consumption after the charging process has been completed.

It should be pointed out that the additional losses of 10 W in the prior and post charging states are based on estimates of power needs to perform the functions, but it is unknown how much power their real implementation consumes, as there is no test data publicly available.

3.1.4 Comparison of Efficiency of Conductive and Inductive Systems during Steady Charging.

There is limited data available to compare the charging efficiency of selected conductive and inductive charging systems. Selected data is shown in Figure 11 and Figure 12, and in Table 3. The efficiency figures for conductive chargers included in this table consider the complete power conversion from grid to battery terminals, whereas the values for inductive systems often do not include the PFC front end[4]. Standards defining comparable conditions (misalignment, air gap, etc.) for efficiency measurements are currently under development (e.g. SAE J2954). However, as of today these are

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[2] As the standards for communication and for LOD and FOD are currently under development the precise estimation of energy losses is not possible.

[3] This does not apply to dynamic charging.

[4] Charging efficiency measurement and results for inductive charging systems are often published as DC/DC efficiencies without the losses of the PFC. Those results are marked in the chart with an asterisk (*).

neither enforced, nor adopted by industry. Therefore, a fair comparison of efficiency data provided by the system manufacturers is not yet possible.

An early suggestion of the standardization taskforce was to require a minimal efficiency 90% from grid to the battery terminals[5].

It can be seen that the efficiencies of inductive chargers are reduced by approximately 2 to 4% compared to the conductive EV chargers. This is mainly due to the limited size available on the vehicle for the receiver coil. Generally, small receiver coils lead to low magnetic coupling, and this is a major contribution to the power losses during steady charging.

As discussed above, the additional losses of an ICS in the prior and post charging state are comparably low.

From Figure 12 it is evident that the power conversion efficiencies of the three examples developed at universities or similar research institutions are noticeably higher than those of the commercial systems developed by companies. This may be at least partially related to the following reasons:

- Charging efficiency measurement and results for inductive charging systems are often published as DC/DC efficiencies without the losses of the PFC.
- The degree of industrialization of the design: Meeting for example the limits imposed by radio frequency disturbance standards (e.g. EMI), stray field limits and other safety requirements often result in a reduction of the charging efficiency.
- The system specification - the range over which the ICS under consideration is operable: The charging efficiency depends to a significant degree on geometrical constraints. There are a number of parameters to take into account when comparing the performance, many of which are not present in conductive systems, such as:
    - The ground clearance range
    - The tolerable misalignment between transmitter and receiver
    - The size and shape limitations due to the construction of a particular vehicle.

  As mentioned above, standardized conditions concerning these parameters are currently under development. Therefore, the tests may represent different situations. An ICS developed at a pure research facility may not necessarily adhere to the same stringent requirement an OEM might require from its suppliers.

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[5] FTA Research “Review and Evaluation of Wireless Power Transfer (WPT) for Electric Transit Applications” page 29. https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0060.pdf

Figure 11 – Efficiency of selected conductive charging systems.

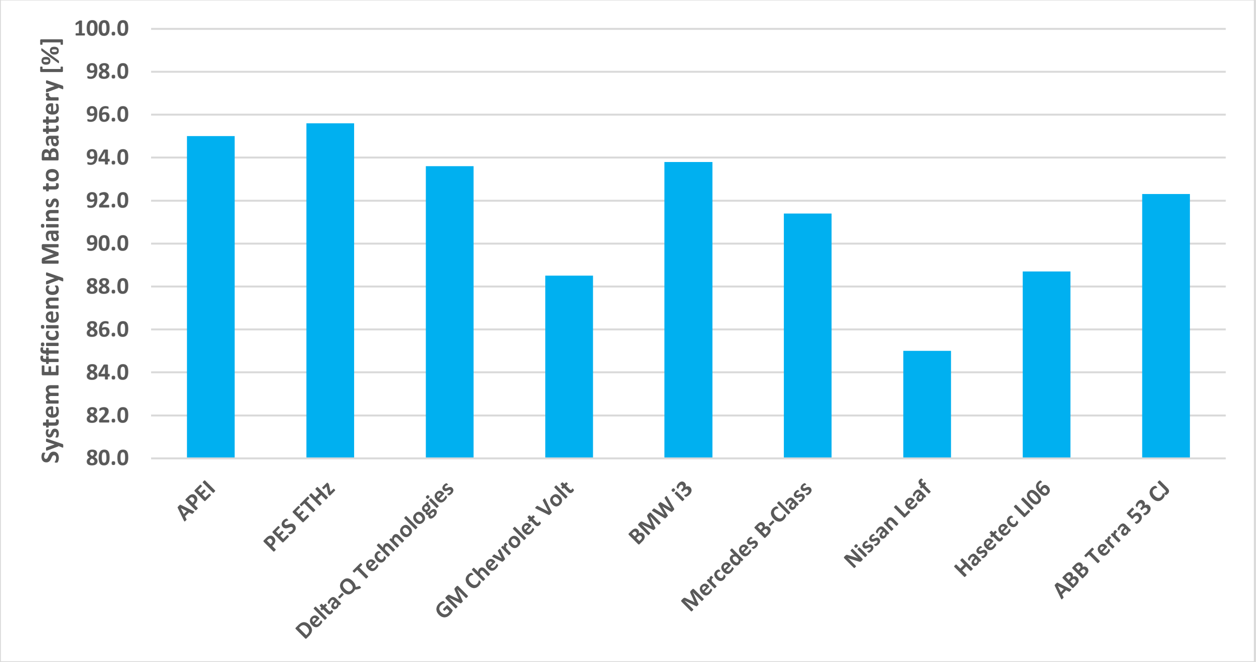
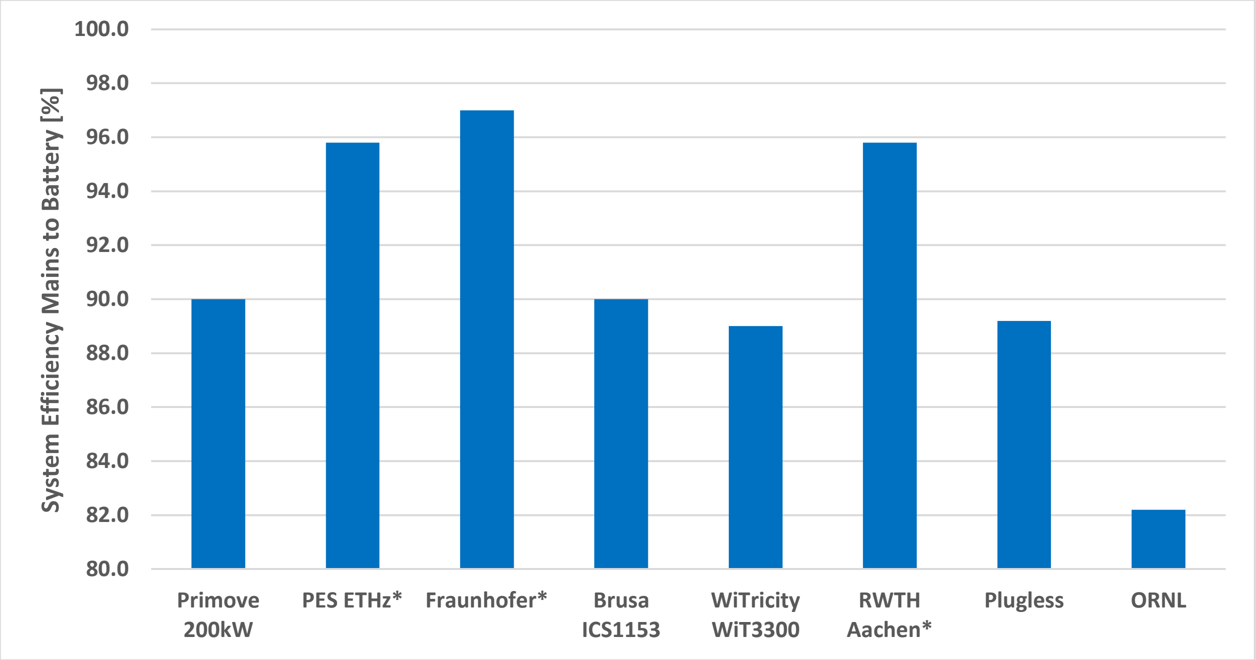


Figure 12 – Efficiency of selected inductive charging systems.



* DC-DC efficiency only, without PFC front end.

Table 3 – Power conversion efficiency of EVSE during steady charging.

Brand/Model	P (kW)	Efficiency (%)
Conductive AC		
APEI	6.1	95.0
PES ETHz	3.7	95.6
Delta-Q Technologies	3.3	93.6
GM Chevrolet Volt	3.3	88.5
BMW i3	6.6	93.8
Mercedes B-Class	7.1	91.4
Nissan Leaf	3.3	85.0
Hasetec LI06	50	88.7
ABB Terra 53 CJ	50	92.3
Inductive		
Primove	200	90.0
PES ETHz*	50	95.8
Fraunhofer*	22	97.0
Brusa ICS1153	3.7	90.0
WiTricity WiT3300	3.3	89.0
RWTH Aachen*	3.0	95.8
Plugless	3.3	89.2
Inductive	7.0	82.2

3.2 Additional Considerations on the Efficiency of ICS

Today the general principles of inductive charging are fairly well understood. However, the number of actually implemented systems in the field is still marginal, and the introduction to the market is in its very infancy. In this process, a number of issues and decisions may affect the final performance, including the efficiency of wireless charging. Some important aspects are discussed next.

3.2.1 Losses due to metallic chassis

Findings from NBT´s own research show that up to 2% of efficiency of ICS is lost due to the presence of the chassis of a vehicle[6]. The electrically conductive material affects the magnetic field distribution and, additionally, causes eddy current losses. If metallic materials would be avoided at least in the proximity of the receiver, the charging efficiency could be increased by 1 to 2%.

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[6] In the Power Electronics Lab at the NTB University of Applied Sciences in Buchs, Switzerland several ICS prototypes were developed ranging from 3.5 kW to 22 kW.

3.2.2 Interoperability

In general, ICS are developed with transmitter and receiver optimized for each other. This is not critical for the low power home based applications. However, the publically accessible chargers must be interoperable between a large number of vehicle brands and models. The strategy of having dedicated charging stations for separate EVs could impede the introduction of ICS to the market.

Currently developed ICS systems use different winding topologies and geometric sizes. Next to the typical circular coil winding, the “double-D” arrangement is popular and favored by several companies and research institutions. As a third variant, also the solenoidal geometry is considered. Depending on the particular requirements either one has its merits. Preliminary studies have shown that interoperability between these systems may be possible, however, only at reduced power[7]. In addition, also a reduced efficiency must be expected.

Similarly, but less critical even for identical topologies, if the geometry or the number of turns on transmitter and receiver windings are not optimized for each other their performance may not be optimal. The same holds if the intended ground clearance ranges of transmitter and receiver do not match.

A final aspect is the operating frequency. For low duty EV applications a standard of 81 to 90kHz seems to become widely adopted. For heavy duty vehicles, with high power chargers, the frequency is commonly set around 25kHz. These two ranges are not interoperable at all.

Based on these facts it is imperative to develop a common standard for inductive charging systems to be implemented in EVs.

4 Future Impact of EVSE

Future impact of EVSE depends on the viewpoint of the stakeholder involved. For example, the view of the vehicle manufacturer differs from the view of the energy provider. The following sections describe possible impact from a technical point of view.

4.1 Impact on the Energy Infrastructure

It is expected that the number of EVs will increase significantly over the next 10 years. That means for residential areas a potential increase of electric power consumption during the evening hours, when most people return from work and charge their EV at home.

This may require a retrofit of the local low voltage grid, including associated transformer stations. In order to avoid this costly measure some utility companies consider implementing local storage equipment for peak shaving. This may even be complemented with a local photovoltaic plant or wind generator. In this case, the efficiency of the storage system must be considered as well in the power conversion chain.

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[7] Omer C. Onar, Steven L. Campbell, Larry E. Seiber, Cliff P. White, and Madhu Chinthavali; *Vehicular Integration of Wireless Power Transfer Systems and Hardware Interoperability Case Studies*; 2016; Oak Ridge National Laboratory; Wei Zhang, Jeff C. White, Arpith M. Abraham, and Chunting C. Mi; *Loosely Coupled Transformer Structure and Interoperability Study for EV Wireless Charging Systems*; 2015; IEEE Transaction on Power Electronics.

In the longer term ICS systems for EVs will likely operate bi-directionally. That means power flow to and from the vehicle battery will be possible. There are several studies[8] showing that a larger number of vehicle batteries can be used to help stabilizing the power grid. In this case, the battery can at least partially replace the local storage mentioned above. The bi-directional functionality must be designed carefully in order to not jeopardize the efficiency of the charger, as well as the live time of the battery.

4.2 Future impact on regulation

The field of inductive power transfer is very new, whereas conductive charging builds on over 50 years of experience in power electronics. Given the intensive research activities worldwide it is reasonable to expect that the charging efficiency of the ICS will improve in the foreseeable future.

A number of organizations and institutions are involved in promoting and supporting electric mobility including the required charging infrastructure in Switzerland. E.g.:

- The Ladenetz Schweiz, with a focus on coordinating the development of a network of charging stations.
- The Verband Swiss eMobility[9], supporting the development of the political and institutional ground for the expansion of e-mobility.
- The Parlamentarische Gruppe Elektromobilität[10], (parliamentary group electric mobility) campaigning for electric mobility in the Swiss parliament.

For the success of electric mobility in general, and of the wireless charging systems in particular, it is important and imperative to establish international standards, regulating and unifying technical key aspects of these systems. Building a number of parallel systems, with no or only limited interoperability is seriously jeopardizing the adoption and success of the ICS. Switzerland will have to align its activities with the standards being currently developed in Europe and worldwide.

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[8] Vehicle to Grid (V2G) or Swiss2Grid, the Swiss version
http://www.acpropulsion.com/icat01-2_v2gplugin.pdf

http://www.s2g.ch/?lang=en

[9] https://www.swiss-emobility.ch

[10] https://www.swiss-emobility.ch/de/Politik/Parlamentarische-Gruppe/